TECHNICAL PAPER

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THERMOCOMPRESSION BONDING

Thermocompression bonding is a quick and easy method to reliably connect flip-chips. As the name suggests, this connecting method relies on force and temperature. This means that numerous bonding processes, basically even eutectic soldering with force as used in laser bar soldering, fall into this category. In literature and among specialists, the term "thermocompression bonding" is not being used consistently, making it difficult to find an exact definition. In the following, we focus on specific thermocompression processes used in combination with gold stud bumps or Indium bumps. Bonding flip-chips with this connection methods has many advantages and shows excellent connection properties. And yet it is still a niche technology – unjustified, as this paper demonstrates! It gives a general overview of the process as well as typical process parameters. The paper also discusses common challenges of employing this technology and shows ways to overcome them with a FINEPLACER® die bonder.

The Process of Thermocompression Bonding

Thermocompression bonding is a diffusion process suitable for wire bonding and flip-chip bonding. For that, the contact pins must be made from ductile material, e.g. stud bumps made from gold wires. The bumps are either applied to the substrate or component. On the opposite side, flat contact pads, preferably made from the same material, are used as bonding partner.

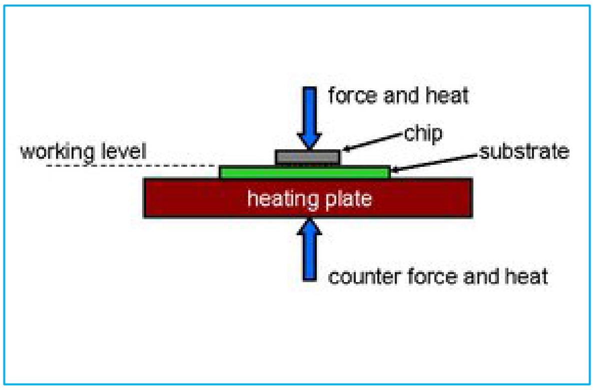

Fig. 1: The principle of thermocompression bonding

Without melting the contact material, a thermocompression process achieves a substance-to-substance bond with sufficient mechanical strength, stability and very good electrical conductivity. Particularly when combined with flip chip bonding, this process improves the RF properties of the bond.

Specifically gold, in the form of stud bumps, is suitable for this kind of process. The stud bumps can be easily created and even stacked with a ball-wedge bonder. The wire diameter determines the bump width and height. As gold is a precious metal, complex cleaning processes prior to bonding and the use of flux is not needed. In particular in development and prototyping, this approach promises quick results.

For smaller bump diameters, galvanic processes are still the go-to method. Here, contacts are made from common materials, such as gold, copper or Indium. Contacts with diameters of only a few micrometers are possible.

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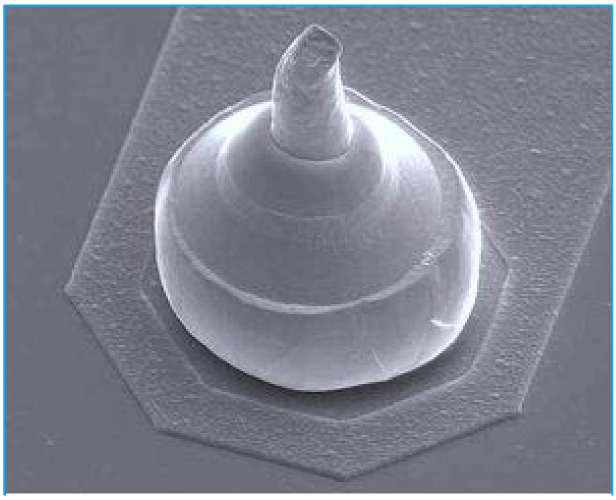

Fig. 2: Gold stud bump, 300x magnification, ø≈50 µm

In order to create a bond using thermocompression with gold stud bumps, component and substrate are heated to approx. 300 °C and then pressed together for approx. 0.5 s to 4 s with a defined bond force. Following the principle of diffusion bonding, a bond is created which is immediately able to withstand stress. The force used for this process is strongly depending on the contact area. With a bump diameter of approx. 50 µm ($A \approx 0.002\ mm^2$), the used force should be 1 N, with surface activation measures further improving the bonding result. However, this also depends on the substrate. On soft materials (e. g. Polyimide), the required force tends to be a bit higher.

Problem with common FC technology	**Solution via TC bonding**
Open soldering contacts caused by insufficient planarity of the substrate, mostly with small bumps, in particular on flex materials	Applied force keeps substrate flat
Common design rules hamper layout of FC soldering pads as tolerances between solder resist and copper tracks are too large in relation to the miniaturized FC.	No solder resist needed
Bad reliability of adhesives in moist environments	Metallic, substance-to-substance bond with high reliability against moisture
Relatively high contact resistance (e. g. adhesive technologies)	Very low contact resistance due to substance-to-substance metal contacts
Worse HF properties with ACF / ACA due to conductive particles between the conductive tracks	Defined and therefore simulatable HF properties
High non-recurring engineering costs folr solder or gold bumping	Simple process setup for stud bumping

Table 1: Advantages of thermocompression bonding

The Advantages of Thermocompression Bonding

As table 1 shows, thermocompression bonding offers numerous advantages compared to common flip chip technology.

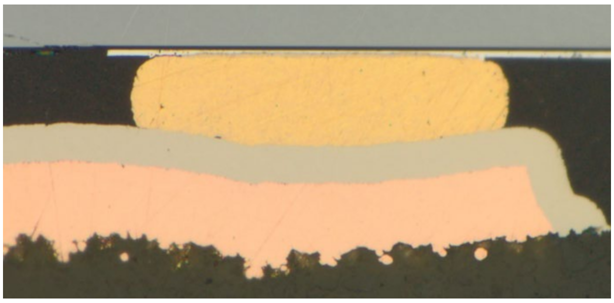

Fig. 3: Thermocompression-bonded chip on board (cross-section, courtesy of AEMtec GmbH)

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The technology is also interesting from a commercial point of view. This is especially true for smaller volumes, as the setup costs for bumping and the thermocompression process are significantly lower compared to e. g. FC soldering. In series, however, bumping is more expensive as it is a serial process. Depending on the specific constellation, there is a critical number of wafers up to which TC bonding is the more economical solution.

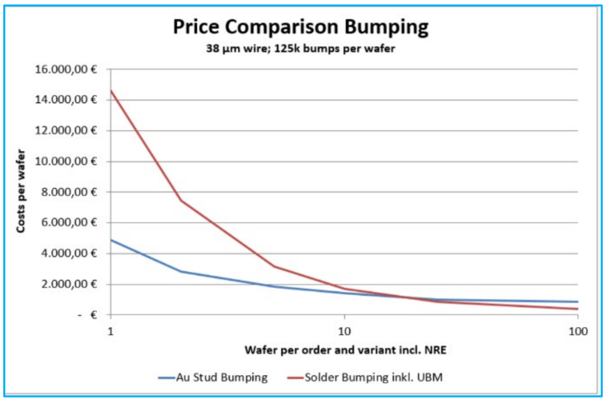

Fig. 4: Comparison of bumping costs

High Placement Accuracy

For good electrical conductivity, high placement accuracy even with small contact areas or many bumps is a requirement.

High placement accuracy is a main focus of Finetech machines. It is ensured by using the FINEPLACER® principle with stationary beamsplitter and only one moving axis, the placement arm. Thanks to the beamsplitter, an overlay image of the contacts on the bottom of the chip and the pads in the target area of the substrate is generated. The overlay image allows the operator to visually align chip and substrate with high accuracy. Due to only one moving axis, this accuracy is kept during the chip placement procedure, allowing for placement accuracies <1 µm. Even more simple FINEPLACER® models offer a placement accuracy better than 5 µm or 10 µm. This means that it is no problem to connect very small contact areas with sufficient accuracy.

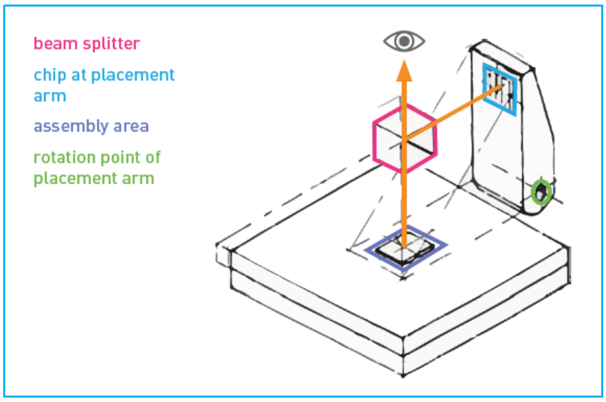

Fig. 5: Overview of the FINEPLACER®principle

High Process Temperatures

For the thermocompression process, temperatures up to 300°C are required in the bonding joint. This is achieved by heating through the chip using a heated tool and by providing additional heat from below using a Substrate Heating Module.

The Chip Heating Modules used in FINEPLACER® system allow a direct heat input from the top. They consist of a control unit and component-specific tooling with integrated heating element and a thermocouple for closed-loop temperature control. This integration, combined with the selected materials, ensures quick thermal input and uniform heat distribution.

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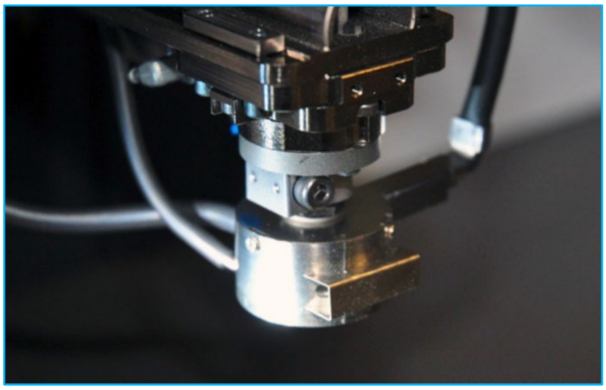

Fig. 6: High-Speed Chip Heating Module

In addition, Substrate Heating Modules are used to preheat the substrate from below as homogeneously as possible and to keep it at a certain temperature level during the thermocompression process. They differ in heated work area, power, maximum possible heating and cooling ramps, and position stability.

The heating modules provide temperatures up to 400°C, sometimes even up to 450°C, giving a lot of leeway in the process.

Large Bonding Force Range

With chips of different sizes and characteristics, the required bonding forces can greatly vary. The die bonder considered for the job has to be capable of supporting this wide force range.

Depending on the type of machine, bond forces between 0.05 N to 1000 N are available (spread across two separate force ranges). This ensures that on the one hand small forces can be fine-adjusted very accurately, while on the other hand also very high forces are available. The force range transition is carried out automatically by the machine.

Special Machine Design

However, not only the pure machine capability is important, but also the process result, e.g. in case of high force or high temperature profiles. With this in mind, the entire design of the machine is engineered to minimize the influence of forces and temperatures on the process result as far as possible.

In order to achieve the best-possible mechanical stability of the placement system, it is de-coupled from the force system. This means the force module can deform itself while the placement remains stable. The substrate heatings are reinforced to ensure they don’t significantly deform during high force loads.

High load capacity and motorized Z-axes even allow for an active yield compensation. As a result, the bonding plane is kept constant even under the force of up to 1000 N.

Thermal expansion of machine parts, tools and assemblies is minimized by using special materials and design. E.g., this results in the center point of the substrate heating to remain stationary even during extensive temperature cycles.

Ensure Parallelism

Gold stud bumps usually have a height of 40 µm to 60 µm, depending on whether they were previously coined. For a substance-to-substance bond and good electrical contacting, they must be pressed onto the opposing contacts over the entire chip area using controlled bonding force. Parallelism between component and substrate may have tolerance of only a few micrometers to

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ensure that also on large components each bump has the same force load.

The FINEPLACER® working principle (the functional square) ensures there is no system-related tilting between substrate and chip. Any tolerances, e.g. in the material, can also be compensated by simply adjusting the parallelism of the placement arm. In addition, gimbal tools with parallelism compensation can also be used. With these, the tool tip is movable and adapts to the placement plane. Tilting can thus be significantly reduced. Since the self-compensating function of these gimbal tools can also be guaranteed under high forces, parallelism is ensured even under difficult conditions.

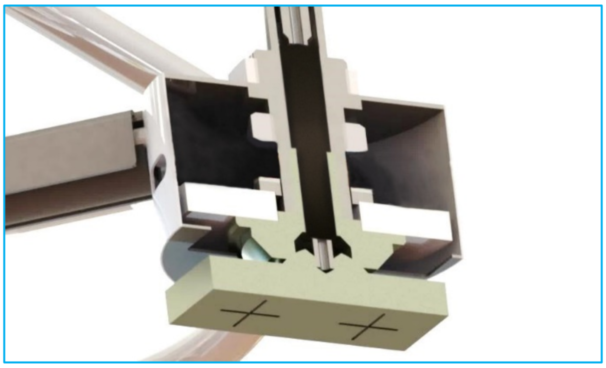

Fig. 7: Cross-section – parallelism compensation integrated in heated tool

Recommended Systems

Finetech offers FINEPLACER® systems for R&D as well as small series production. They are primarily distinguished by their placement accuracy, the degree of process automation and the available process modules and parameters. Common to all FINEPLACER® systems is that the parameter range of the individual process modules is large enough to ensure that there are always enough reserves available to avoid reaching the limits of the device in terms of the parameters required for the process. It therefore operates in the optimum range and allows sufficient scope for process optimization.

Finetech recommends the following FINEPLACER® systems for thermo-compression bonding:

The FINEPLACER® pico ma is the ideal laboratory bonder for small volumes. Its technology spectrum covers practically all common chip bonding technologies. It can be very flexibly configured, converted and retrofitted. Since it is a manual device, new processes or products can be set up in a few minutes. With its placement accuracy of <3 µm and configured with a heating plate, a chip heating module and a manual bonding force module up to 400 N, it is optimally equipped for thermocompression bonding at a comparatively low investment.

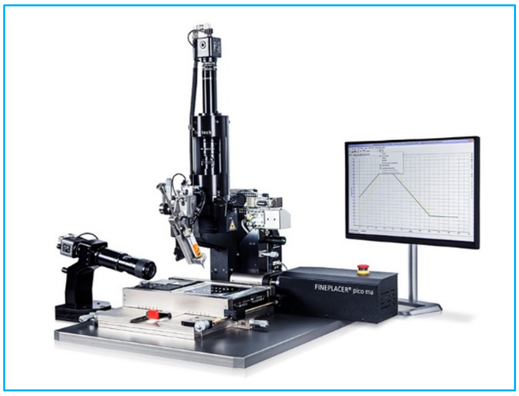

Fig. 8: FINEPLACER® pico ma

The FINEPLACER® femtoblu is particularly suitable for automated development and small series production.

With a placement accuracy of 2 µm @ 3 sigma, the system offers maximum process flexibility for prototyping and production environments.

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Fig. 9: FINEPLACER® femto blu